Mechanical Condition Diagnosis of Power Transformer by FRA using AI Technique

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Abstract— There are many methods of fault diagnosis of Power transformer but among all these Fra is the most suitable method for electrical and /or mechanical faults of a transformer. The concept of FRA has been successfully used as a diagnostic technique to detect the winding deformation, core and clamping structure of power transformer. In FRA measurement, the nine statistical indicators are used to detect the deviation in FRA signature. The effects of different winding parameters on FRA signature are described. The artificial neural network approach has been proposed to complement these nine indicators. ANN can be used to increase the efficiency and accuracy of diagnosis system. Neural network toolbox is used to train the multilayer feed-forward neural network. Different practical case studies and their data are used to train and test the multilayer feed-forward neural network. In this work Matlab-2014 is to be used. This paper presents the review of ANN with its relative advantages.

Key words: Transformer, FRA, ANN, winding parameters

I. INTRODUCTION

Power transformers are expensive and important units in electric power networks. In 1831, Michael faraday had carried out many experiments for demonstrating the principle of electromagnetic induction. The electricity was produced in first time from magnetism occurred on 29th August 1831. Faraday's invention contained all the basic elements of transformers - two independent coils and a closed iron core. The transformers are being mechanically stressed out of service due to transportation and mishandling in the course of an installation. Over the past few decades, a number of diagnostic methods have been developed for monitoring the health of transformers. There are many methods such as SCI (short-circuit impedance measurement), FRA (frequency response analysis), LVI (low voltage impulse), etc. The Short Circuit Impedance Measurement is not widely used on site because its sensitivity is low and the hidden trouble cannot be found effectively. On the other hand, the sensitivity of FRA and LVI is high. FRA is a powerful and sensitive diagnostic test technique to winding displacements. It is now being standardized by both IEEE and CIGRE. In this paper, the basic introduction is carried out in section II and history of FRA in section III. Section IV explains how SFRA is carried out. Section V explains the variation in SFRA plot due to variation in winding parameters. Section VI explains the case study using artificial neural network.

II. WHAT IS FRA?

FRA is a comparison based technique [1,2]. Comparisons are taken according to time, type and phase of the transformers. Among all these, time comparison is more reliable. Phase comparison is only option for old transformers.

Today, FRA measurements are carried out by dedicated instruments most of which employ the swept frequency method and only a few follow the impulse response method. The Frequency Response Analysis (FRA) can detect the type of fault and the exact location of fault. In FRA, Impedance measurement of transformer winding is carried out over a wide frequency range and then the results are compared to the reference set. When variation is found, it may indicate the damage to the transformer. Frequency response analysis can detect many type of faults includes short circuit fault, interturn fault, failure of transformer oil and mechanical displacement.

Transformer winding is nothing but an RLC network. Any type of fault occurs it may result the change in this RLC network. Due to these changes the frequency response may change, either it may peak or valley. The different Statistical indicators[3] such as Correlation Coefficient(CC), Mean Square Error(MSE), Root Mean Square Error(RMSE), ASLE, Absolute difference(DABS), Min Max Ratio(MM), Sum Squared Error(SSE), Sum Squared Ratio Error(SSRE), Sum Squared Min Max Ratio Error(SSMMRE), etc. are used to detect the faults in the winding.

III. BRIEF HISTORY OF SFRA

Frequency Response measurements were first investigated in depth by Dick and Erven at Ontario Hydro in Canada in 1970. In 1978, E.P. Dick first used Frequency Response Analysis to detect transformer winding deformation. In 1980, the Central Electricity Generating Board (CEGB) in the UK took up the measurement technique and applied it to transmission transformers.

In 1978, “Transformer diagnostic testing by frequency response analysis”, IEEE Trans. Power App. Syst., vol. PAS-97, no. 6, pp. 2144–2153, was presented by E. P. Dick and C. C. Erven. They contributed to further knowledge of their use for transformer diagnostics.

In 1980, further research carried out by Central Electricity Generating Board in UK.

From 1988 to 1990, proving trials by European utilities, the technology cascades internationally via CIGRE, EuroDoble and many other conferences and technical meetings.

In 2002, “Methods for comparing frequency response analysis measurements,” in Proc. 2002 IEEE Int. Symp. Electrical Insulation, Boston, MA, 2002, pp. 187-190 was published by S. Ryder. Comparison between two statistical methods was carried out to compare FRA response curves.

In 2003, “A new technique to detect winding displacements in power transformers using frequency response analysis", Power Tech Conference Proceedings, 2003 IEEE Bologna, Volume 2, 23-26 June 2003 Page(s):7 pp. Vol.2 was published by Coffeen, L.; Britton, J.; Rickmann, J. The objective of this paper is to calculate quantitative indicators to indicate fault situations.

In 2004, First SFRA standard, "Frequency Response Analysis on Winding Deformation of Power Transformers", DL/T 911-2004, is published by The Electric Power Industry Standard of People's Republic of China.

In 2008. "Mechanical-Condition Assessment of Transformer Windings Using Frequency Response Analysis (FRA)" is published by CIGRE report 342.

Thus, from 1991 to present, Results & Case Studies were published and presented, validating the FRA method.

IV. BASIC CIRCUIT OF SFRA

In recent years, the FRA technique gained popularity because of its sensibility to failures, such as winding displacements, deformations, and electrical failures. FRA method is based on the evaluation of transfer function [4] by means of statistical and mathematical indicators which are evaluated in several frequency bands. The normally used frequency range is 20Hz to 2MHz.

Two terminal pairs of transformer are chosen as input and output as shown in Fig. 1. SFRA is performed by applying low voltage signal of varying frequencies to the transformer winding and the measurements of both input and output signals are taken. Now, the ratio of output to input signal gives required response. And this output to input signal ratio called transfer function of transformer from which both the magnitude and phase can be obtained. Any geometrical deformation changes the RLC network, which in turn changes the transfer function at different frequencies.

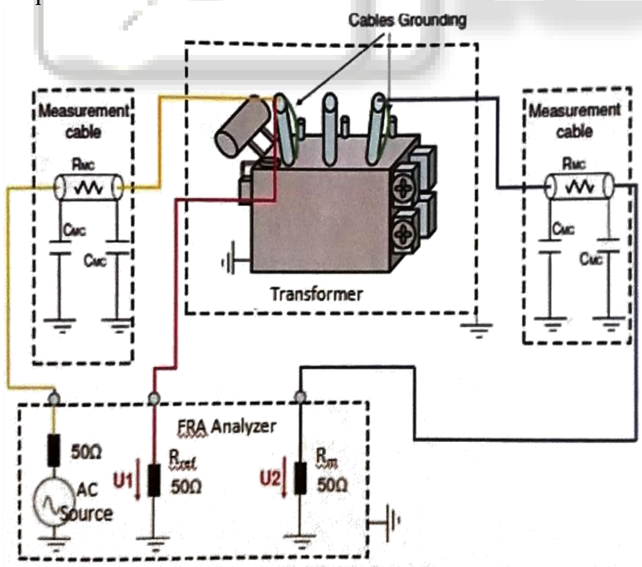

Fig. 1: SFRA measurement layout

V. EFFECTS OF DIFFERENT WINDING PARAMETERS

Frequency response of the transformer winding is sensitive to the physical parameters shown in Fig. 3. of the transformer winding. When these parameters changes, the different types of fault occur.

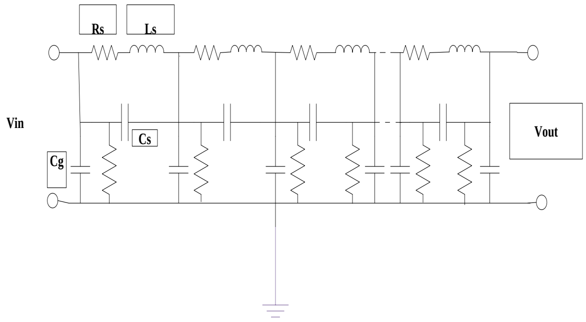

Fig. 3: Transformer winding parameters

Physical parameters	Types of faults
Inductance	Disc deformation, Local breakdown, Winding short circuits
Shunt Capacitance	Disc movements, Buckling due to large mechanical forces, Moisture ingress, Loss of clamping pressure
Serial Capacitance	Aging of insulation
Resistance	Shorted or broken disk, Partial discharge

Table 1: Effects of winding parameters

Effects of different parameters are listed here:

- Effect of self /mutual inductance.
- Effect of Series capacitance.
- Effect of Series resistance.
- Effect of Shunt capacitance.

A. Effect of Self/Mutual Inductance:

When increasing the inductance [8] will shift the resonance and anti-resonance frequencies to the left over the entire range of frequency. It will also have a minor impact on the amplitude. And decreasing the inductance value will shift the resonance and anti-resonance frequencies to the right when compared with the base values signature.

B. Effect of Series Capacitance:

There are no variations in low frequency and medium frequency region when capacitance increased or decreased. So no impact in FRA signature in low and medium frequency region. And In both cases resonance and anti-resonance frequencies will shift to the right.

C. Effect of Series Resistance:

When increasing the value of the series resistance will introduce minor impact on the amplitude in the medium and high frequency range. Also, some high frequency resonance frequencies will shift to the right. Decreasing the value of the series resistance will not have any impact on the FRA signature except in the very high frequency range where the amplitude will be slightly affected.

D. Effect of Shunt Capacitance:

The effect of increasing shunt capacitance is more visible in the high frequency range, where resonance frequencies will shift right with little impact on the amplitude. On the other hand, decreasing shunt capacitance will affect the amplitude of the FRA signature in the entire frequency range and resonance frequencies in the medium and high frequency range will be shifted to the right.

VI. CASE STUDY

Case I. A three phase auto transformer with tertiary winding of rating 315 MVA, 400/220/33 kV and 50 Hz is manufactured for EMCO Ltd. Thane. The SFRA plot is shown in Fig. 4.

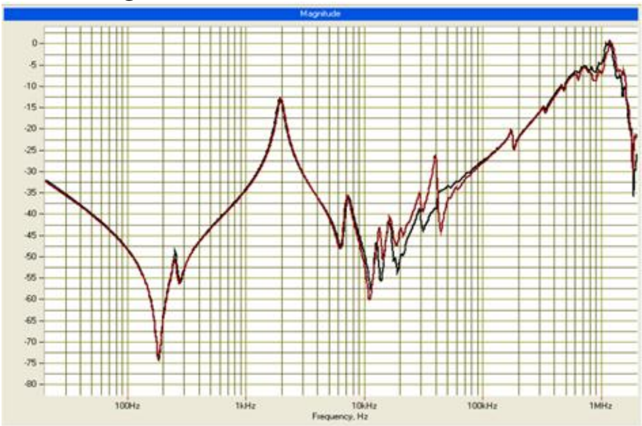

Fig. 4: SFRA plot for case I

In Fig. 4 Black color response are taken first at factory. Red color response is taken second at field after commissioning. As shown from Fig. 4. Changes are between 10 kHz to 60 kHz which is due to tap position. The tap changer was diverting type and both responses has been taken at normal Tap 9b but previous tap in both case was different. In one previous tap were 8 and in second previous tap was 10.

The different nine statistical indicators have been calculated between different frequency ranges from the SFRA plot shown in Fig. 4. The Neural network is used to increase the stability and accuracy. Normalized value of nine Statistical indicators is used as input of the neural network and output value is between zero and one. In this case, the numbers of hidden layer neurons is 10 which gives a better training performance.

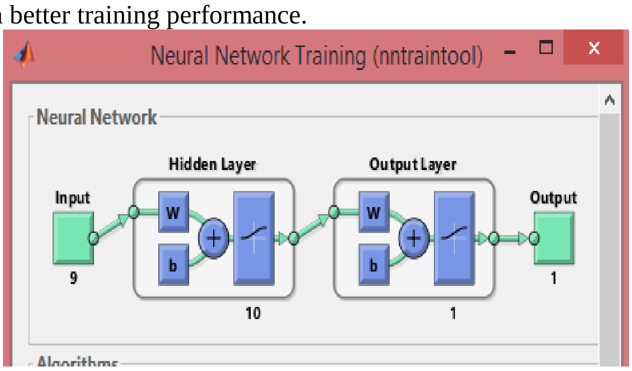

Fig. 5: Neural network

After the NN is created, it is trained. In this case, Levenberg-Marquardt is used as training algorithm. From the Fig. 6. It can be observed that best validation performance is achieved at epoch 17. After completion of training of neural network, the next step is validating the network. Validation of neural network is done to check the network performance and retrain the network. The next step is to observe the regression plot which is shown in Fig. 7. The regression plot which indicates the relationship between the outputs of network and targets. If the training were perfect, the network outputs and targets would be exactly equal. But this relationship is rarely perfect in practice.

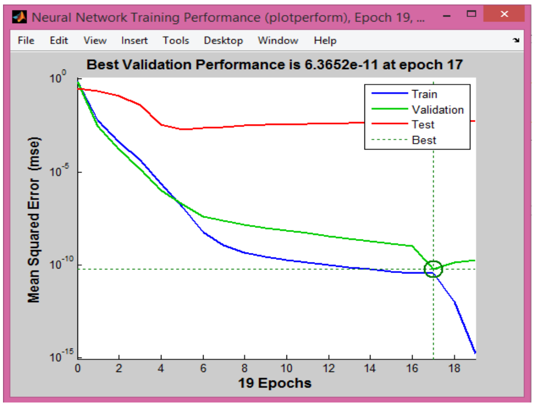

Fig. 6: Neural network performance

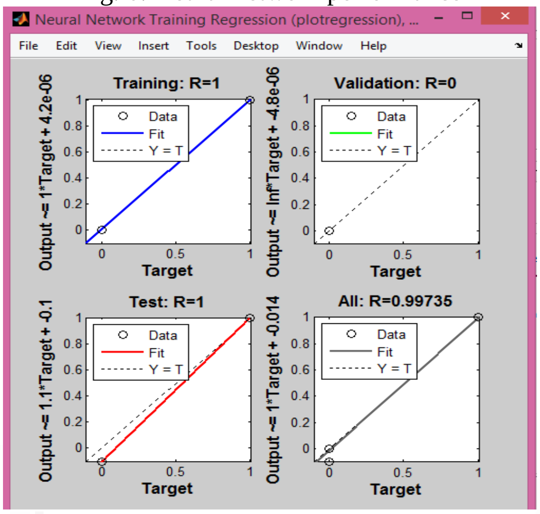

Fig. 7: Neural network regression analysis

After validation of the network, the ANN is tested using the different field data which are not introduced during the training process. The network is tested by different case studies data.

VII. CONCLUSION

ANN can be used to increase the efficiency and accuracy of diagnosis system. The important advantage of ANN based fault diagnosis is that it can learn directly from the training samples and update its knowledge when necessary. ANN computational complexity is not too high, specially in testing process. The application of ANN makes possible to reduce considerably the laboratory experiment time and it requires no physical models.

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